Chapter 1

Introduction

1.1 Background

The report on annual energy outlook [1] indicates by year 2040 over 50% of new generation capacity would come from renewable and nuclear. While new coal-fired plants in India represent nearly half of the net coal capacity added worldwide. In order to meet the increasing load demand and to achieve the percentage further (i) need to install expensive spinning reserves, (ii) thus resulting wear and tear of thermal units, and (iii) the inability to achieve adequate voltage are still the drawbacks of conventional power system [2].

with the increasing concerns about the limited fossil fuel resources, their impact on the environment, especially the global warming and the harmful effects of carbon emissions have created a new demand for clean and sustainable energy sources. The Wind and solar power generation are two of the most promising renewable power generation technologies. Fuel Cells (FCs) also has potential to be considered as one of the green power sources of the future. However, each of the aforesaid technologies has its own drawbacks. For instance, the wind and solar power are highly dependent on climate while FCs needs hydrogen-rich fuel. Nevertheless, because different alternative energy sources can complement each other to some extent, multi-source hybrid alternative energy systems (with proper control) have great potential to provide higher quality and more reliable power to customers than a system based on a single resource. Because of this feature, hybrid energy systems have caught worldwide research attention. A hybrid system can supply power either AC or DC or both. In a hybrid power system component or system control or both are utilized to regulate power in a hybrid power system [3, 4].

The development of distributed Photovoltaic system is noticeable by the addition of 14730 MW grid-connected Photovoltaic generation system in the US in 2016-nearly a 50% rise in capacity from 2015 [5]. In addition, wind generation is growing and widely utilized renewable energy technology in power systems. The wind turbine generators have attracted an accelerated installations in recent years. In the end of 2015, wind power installed capacity has reached more than 432.42 GW worldwide and by the end of 2016, this value has grown up to 630.875 GW, which represents a growth of 45.9% in a year [6].

Individual Wind and PV power systems have made a successful transition from small stand-alone sites to large grid-connected systems. The utility interconnection brings a new dimension to the renewable power economy by pooling the temporal excess or the shortfall in the renewable power with the connecting grid that generates base-load power using conventional fuels. This improves the overall economy and load availability at the renewable plant site — the two important factors of any power system. The grid supplies power to the local loads when needed or surplus power is injected into the grid when available [7].

Two important parameters to access the grid stability are the system voltage and frequency. These two have to be continuously controlled to maintain them within acceptable limits. Frequency deviation occurs due to an imbalance between generation and load or sudden increase or decrease of the load. The load is dynamic in nature and the generation has to be controlled to keep track of the load variations and follow the dynamics. In order to overcome this problem, an automatic generation control (AGC) came into existence, which forms the basis of the proposed research. The main focus of the research is the problem of operating the system in a continuous automatic closed-loop control so as to maintain the voltage and frequency within acceptable limits [8].

In the conventional power system, the generators are equipped with two major control loops, namely:

i. Automatic Voltage Regulator (AVR)

ii. Automatic Load-Frequency Control (ALFC) or AGC

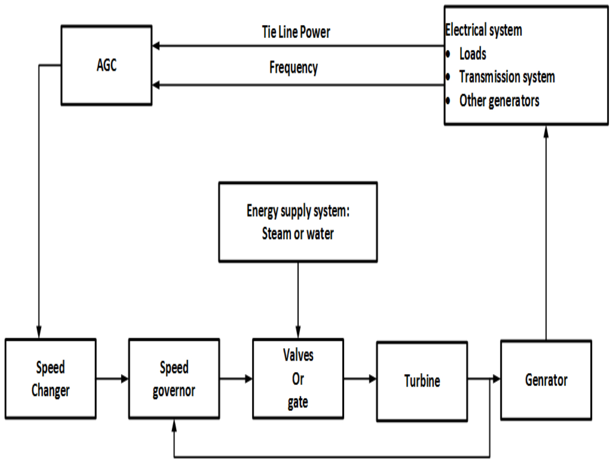

FIGURE 1.1: Functional block diagram of power generation and control system

The ALFC, also called AGC, controls the real power so as to maintain the system frequency constant as shown in Figure 1.1. This is achieved by controlling the speed of the prime mover. The ALFC does not comprise a single loop. It has a fast primary loop which responds to frequency changes (due to load changes) and regulates the steam or water flow via the speed governor and control valves to match the real power output with that of the load. The time period considered is of few seconds and this primary loop performs a coarse speed or frequency control.

There is a slower secondary loop which maintains fine frequency adjustment to maintain proper active power interchange with other interconnected networks via tie lines. This loop is insensitive to fast load and frequency changes and acts on deviation which takes place over several minutes. With the primary speed control, we have a steady-state speed (frequency) deviation for a change in the system load. The amount of frequency deviation depends on the governor droop characteristics and frequency sensitivity of the load. All the generating units will change their generation in response to the load change.

Acquisition of frequency to the scheduled value requires additive control to alter the load reference actual points. This secondary control, called AGC, becomes the basic means of controlling prime mover power to match the variations of the system load. The controller should satisfy the following:

• Stable closed loop control operation,

• Keep frequency deviation to a minimum,

• Limit the integral of the frequency error,

• Divide the load economically.

In an isolated system as considered, there is no interchange power to be considered. The function of the AGC is pure to maintain the frequency at the scheduled value. This is achieved by adding a proportional integral controller in the feedback path to change the load reference setting depending on the frequency deviation. It is known that the steady-state error of proportional integral controllers is zero from the control-theory [8, 9].

1.1.1 Brief Review on Traditional LFC / AGC for Conventional generation:

M.L. Kothari, P.S. Satsangi, J. Nanda, et. Al [10–21] have worked extensively on LFC / AGC of conventional interconnected two, three, multi-area systems. A linear discrete-time state-space model for a two-area reheat thermal system was conducted to implement the classical controllers in the discrete-mode using the maximum margin of stability and Integral Square Error (ISE) concepts. In addition application of the parameter plane technique has been demonstrated in the study of the stability, sensitivity and optimization aspects of an A.G.C system. It was observed that a system containing reheat turbines gives more frequency and ties deviations and has a slower response than the system containing non-reheat turbines. The optimum controller setting for an unconstrained AGC system is found to be unacceptable for a constrained system. The analysis reveals that in the presence of generator rate constraint a simple integral controller can perform equally as well as compared to that of a more involved controller based on modern optimal control theory on a hydrothermal interconnected system a continuous- and discrete-mode optimization of integral controllers using an integral squared error criterion is suggested for AGC.

Moreover, for AGC, the optimum integral gains in the discrete mode is achieved by neglecting the generation rate constraints from the mathematical model, in contrast to the case in the continuous mode. The optimum integral gain setting of the thermal area is practically independent of the integral controller setting of the hydro area. A maiden attempt is made to examine and highlight the effective application of bacterial foraging (BF) to optimize several important parameters in automatic generation control (AGC) of interconnected three unequal area thermal systems, such as integral controller gains (KIi)for the secondary control, governor speed regulation parameters (Ri) for the primary control and frequency-bias parameters (Bi), and compare its performance to establish its superiority over genetic algorithm (GA) and classical methods. Comparison of convergence characteristics of BF, GA, and classical approach reveals that the BF algorithm is quite faster in optimization, leading to a reduction in computational burden and giving rise to minimal computer resource utilization. Various techniques in the A.G.C of Interconnected system have been investigated, which includes Proportional Integral (PI), Proportional Integral Derivative (PID),Proportional-Derivative (PD), Integral Integral Derivative (IID), Fuzzy Logic Control (FLC), Fuzzy PI, self-tuning FLC, Particle Swarm Optimization (PSO)-based FLC, Artificial Neural Network (ANN), Bacterial Foraging (BF) technique based on Genetic Algorithm (GA), and self-tuning Fuzzy PI Controller. But these techniques were implemented in the conventional power system.

1.1.2 Brief Review on Interconnected RES generation:

An autonomous hybrid generation system consisting of wind turbine generators (WTG), solar Photovoltaic (PV), diesel engine generators (DEG), fuel cells (FC), battery energy storage system (BESS), ultracapacitors (UC) and aqua electrolyze (AE) has been established. A PI controller using PSO techniques for stand-alone hybrid energy generation/energy storage system was implemented in [22]. However, the power system frequency deviates for sudden changes in load or generation or the both. The comparative performance of the controllers installed to alleviate this frequency deviation for different hybrid systems is carried out using time domain simulation.

A multi-area Automatic Generation Control (AGC) scheme with Wind Turbine Generation (WTG) System connected to the conventional power system was established. The technique proposed analyzes the effect of WTG system on frequency regulation of the conventional power system. Developed technique utilizes a PID controller to control the output of the generators. The parameters of PID controller have been tuned utilizing Genetic Algorithm (GA) based performance analysis. The functioning of proposed scheme has been tested on a 75-bus Indian power system network [23].

A grid-tied distribution system with concentrated or distributed PV generation similar to that of a micro-grid is considered. As the penetration of renewable resources into the conventional grid is higher, the investigation is necessary to have the knowledge of fluctuations that can be produced by PV generation. In order to investigate, a simplified grid model (SGM) is developed on the distribution side to resemble the behavior of the actual grid at that side [24]. Governor droop control was established for the grid connected system in this study.

Various researchers have proposed techniques in developing an interconnected system with the wind and with a diesel generator, PV with a diesel generator, wind-PV with SMES. Various effects are studied for an interconnected power system. It has been observed that a number of researchers have worked on PV-wind hybrid power system in terms of improving the MPPT tracking algorithm, optimal placement of PV-wind or combination of RES sources, energy management system, and optimization techniques for sizing of RES generation [25–27].

1.1.3 Motivation for Research:

Incorporation of renewable energy sources (RES) into the conventional system have many constraints as the RES generation cannot be considered as a constant source of power. The power output totally relies on the climatic conditions such as wind speed, solar illumination for respective power generation. In order mitigate the fluctuations various researchers have come up with different topologies involving a diesel generator or energy storage device in combination with RES generation.

With the incorporation of storage devices into the system we are limiting the performance of the system. In turn adding extra cost, maintenance, replacement of storage device with time, etc... which will affect the efficiency and reliability of the system.

In order to overcome the above backdrop and to improve the effective use of RES generation a new topology is proposed known as the Hybrid system. A Hybrid power system is a combination of two or more RES generations with complementing nature. The selection of RES generation depends on the geographical conditions of the place of installation. A control technique implementation of hybrid power system such that the power generated from one source compliments the other, by extracting Maximum power from RES generation, and control the tie-line power interchange in an interconnected system. The storage element can be eliminated from the system and the power extracted from the RES is used for local load and excess power is injected into the grid is the motivation for the research. considering various parameters in the design of a Tie-line frequency-bias controller to achieve the task of maintaining the voltage and frequency of the system with real time data of environmental conditions measured at the location and different loading conditions. Under investigation of various topologies, the environmental conditions are assumed to be constant or simulated at Standard Test Conditions (STC). In order to simulate, evaluate the performances of a PV-Wind hybrid system for a particular location it is essential to analyze the solar irradiation levels and wind speed profile for that particular location. Few works were reported for north-east India, Rajasthan in India, Kenya, Nicosia, Cyprus and Nice, France etc. The researchers have concentrated on the modeling standalone hybrid power system and comparing the performance of the system for different locations, the optimal sizing coefficient of the hybrid power system, disaster management systems.

From the literature review, it appears that no study has been carried out up till now regarding PV-wind integrated hybrid power system and interconnection of non-conventional energy sources and designing a tie-line frequency-bias control utilizing the effects of change in environmental conditions for South-East India. With the above backdrop, a simulation study of PV-wind hybrid power system with the data of the wind and solar insolation recorded at the location has been carried out to examine the amount of power that can be extracted from the environmental conditions at the location.

1.2 Aim, Objectives and Organization of Thesis

The main aim of this thesis is to

- To avoid storage devices,
- To mitigate the fluctuations caused in output frequency, voltage due to modification in Solar irradiation and Wind speed,
- To mitigate the Voltage and frequency fluctuations caused due to load change in the system,
- To develop a Tie-line Frequency Bias controller to control the power interchange between two areas by maintaining voltage and frequency of the system in specified limits.

The techniques based on Discrete PLL and Droop characteristics based control will be considered for enhancement and restoration of Tie-Line frequency by improving the Voltage profile and Power exchange by utilizing the real time data of solar illumination, Wind speed measured at BITS-Pilani, Hyderabad Campus.

To investigate the performance of the Tie-line frequency bias controller, it is highly desirable to develop a mathematical model of PV-Wind hybrid power system with the control techniques and investigate the performance of the control technique under varying environmental and load conditions. Such techniques have been presented and verified by digital simulation in this thesis.

The objectives of this thesis are as follows:

1. Developing a Mathematical model of a hybrid power system consisting of interconnected Solar Photovoltaic (PV), Wind power generation without storage devices.

2. A Fuzzy Logic Control (FLC) based Maximum Power Point (MPP) tracking algorithm is implemented to improve the performance of the system. To investigate the dynamic response of the FLC under different scenarios of load demand and environmental conditions using MATLAB, Simulink.

3. Based on conventional Load Frequency Control (LFC) / Automatic Generation Control (AGC) the LFC technique for the PV-Wind hybrid system will be studied i.e. Discrete PLL, Droop Characteristics based control techniques.

4. To study of Discrete PLL based Load Frequency Control (LFC) of the stand-alone PV-wind hybrid power system. Performance analysis of the controller under varying environmental and load conditions. A comparative analysis of prediction techniques of wind speed and solar illumination.

5. To study the Droop characteristics based LFC and comparing the performance of the LFC with Discrete PLL based technique to obtain the better control technique.

6. Based on the results, Implementation of Flat Tie-Line frequency control of Interconnected PV-Wind Hybrid Power system.

The present research work is presented in seven chapters. In addition to the current chapter, there are five other chapters that cover mathematical and theoretical analysis of current work. These chapters are as follows:

Chapter 1: The aims and objectives of the proposed research have been set in this chapter that will be covered in this thesis. Finally, the organization adopted in the thesis have been highlighted. A survey of the literature on various Load frequency control techniques in interconnected two-area, multi-area systems, and the Tie-line frequency control techniques. Various control techniques proposed for interconnected Renewable Energy Generation (RES). Based on the literature survey, the chapter concludes highlighting the research gaps that are being taken forward in the successive chapters.

Chapter 2: In this chapter, a survey of the literature on various Load frequency control techniques in interconnected two-area, multi-area systems, and the Tie-line frequency control techniques. Various control techniques proposed for interconnected Renewable Energy Generation (RES). Based on the literature survey, the chapter concludes highlighting the research gaps that are being taken forward in the successive chapters.

Chapter 3: This chapter explains introduction to Hybrid Power system under consideration and Mathematical Modeling of the Photovoltaic (PV) based generation feeding DC load. In this chapter a detailed discussion of mathematical modeling of PV cell. A comparative analysis of PV cell model simulated in MATLAB, Simulink to select an accurate model to build PV based generation. Followed by the implementation of a Boost converter with MPPT algorithm connected to DC load.

Chapter 4: In this chapter, mathematical modeling of Wind-based generation feeding DC load. Detail mathematical modeling of Wind-based generation system consisting of Permanent Magnet Synchronous Generator (PMSG), diode rectifier, a Boost converter, MPPT algorithm. A model based design of Wind-based generation system connected to DC load is simulated in MATLAB, Simulink.

Chapter 5: In this chapter, PV-Wind hybrid power system feeding a DC load with Real-Time data of environmental conditions is implemented. In order to improve the performance of the system, a Fuzzy Logic Control based MPPT algorithm is realized. The performance of the FLC-based MPPT algorithm is investigated under varying environmental and load conditions.

Chapter 6: In this chapter, the real-time data of solar illumination and wind speed measured at BITS-Pilani, Hyderabad campus are utilized to predict the long term and short term solar illumination and wind speed for the location. Further this can be utilized for predicting the amount of power that can be generated from the hybrid power system.

Chapter 7: In this chapter, Load Frequency Control (LFC) technique implementation for stand-alone PV-Wind Hybrid Power system will be investigated. A Discrete PLL based technique and Droop characteristics based techniques are investigated under different load conditions with real-time data of solar illumination and wind speed. The control technique with enhanced performance will be selected for further investigation.

Chapter 8: In this chapter, Grid connected PV-wind hybrid power system and Flat Tie-line Frequency Control of Interconnected PV-Wind hybrid system is implemented in MATLAB, Simulink. The performance of the control for the two-area system is investigated with real-time data of environmental conditions and load change in one area.

Chapter 9: Finally, this chapter summarizes the specific contributions of the current study and conclusions gained from this research. Further, future scope and directions for research in this area have also been presented.